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# RESERVOIR ASSOCIATED EARTHQUAKE RISK IN NORTHWEST HIMALAYAS AND PENINSULAR INDIA

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## ABSTRACT

Seismic activity around Pong, Pandoh, Bhakra and Salal dams in Northwest Himalayas has been reviewed in relation to filling of the reservoirs. The pattern of seismic activity around Bhatsa and Koyna regions has also been examined in detail. It has been found that no significant increase in seismic activity has occurred in and around the dams in Northwest Himalayas so far. The seismic activity around Koyna and Bhatsa dams could be examined in terms of modified asperity models of Kanamori (1981). The model proposed for the Koyna seismic activity after the main shock when applied to Bhatsa region predicted successfully the recent earthquake of 2 June 1990 (M 4.0). According to this hypothesis the magnitude of the largest earthquake in these two regions would not exceed that of the largest aftershock which had occurred after the main earthquake and would be gradually decreasing with time in magnitude at progressively larger recurrence interval.

## INTRODUCTION

During the last 25 years, earthquakes around dams are causing concern to the seismologists throughout the world. Different mechanisms have been proposed to explain their occurrence in the vicinity of the reservoirs but a critical review (Srivastava et al. 1990) has indicated that the phenomena cannot be uniquely explained particularly after all the statistical criteria summarised by Gupta and Rastogi (1976) are applied for these earthquakes vis-a-vis normal tectonic earthquakes. Although experimental evidence suggests that the presence of thrust faulting is not conducive to the reservoir induced seismicity which could be one of the causes for lack of correlation between the reservoir and level and seismic activity in the Himalayas (Srivastava and Dube, 1982). The complexity of the source mechanism of the earthquakes in these regions makes the problem more difficult. For example around Kangra region, earthquakes had been found to have normal faulting as well as thrust faulting with strike slip component. Considering the number of reservoir associated cases with the number of dams, this ratio works out to be exceedingly small. The number of such cases appears to increase with more sophisticated analysis techniques and better instrumentation. The object of this paper is, therefore, to examine whether there has been any significant increase in seismicity after filling up of the reservoir around Pong, Pandoh and Salal dams in Northwest Himalayas. Also the asperity model (Kanamori 1981) modified for Koyna and Bhatsa region (Srivastava et al. 1990) has been discussed which provides us the quantification of earthquake risk around such dams following the occurrence of the main shock, thereby enabling us to reduce panic even if a temporary spurt in the seismic activity takes place.

## Tectonics and Instrumental Set-up

This has been discussed earlier in several papers (Srivastava and Dube, 1982). It may be interesting to note that the nature of seismological observations started functioning much earlier than that of the filling time of the reservoir of Pandoh and Pong dam; thus providing an unique opportunity to take up a study of reservoir induced seismicity in respect of these dams. The network of local seismological stations around Pong and Pandoh dams was increased from 10 stations to 14 stations to cover the Salal Hydroelectric dam. Also the seismic activity around Bhatsa region which was being monitored through 8 seismological stations is now being detected through a UHF Seismic Telemetry Network indigenously designed by Bhabha Atomic Research Centre, Bombay, providing the desired accuracy for the focal depth determination for the local earthquakes.

## Seismic Activity Around Dams in Northwest India

Srivastava and Dube, (1982) had found that the location of epicentres of earthquakes in the region are by and large to the northeastern side of the dams implying their association with the main boundary faults. The focal depths of the events vary from 5 to 30 km, with relatively deeper events located away from the faults justifying the northeasterly dip of the geological faults. Slight increase in the number of earthquakes after filling the reservoir was noted. However, there is no significant change in the number of events recorded within 25 km radius at Sundernagar observatoty close to Pandoh dam. Similar relative comparison is however not possible due to reduction in the magnification of the instrument at Pong after the impounding of the dam. It is nevertheless noticed that there is no significant change in the number of events of magnitude 3 or more on Richter Scale at either of the two dams before and after the filling of the reservoirs.

It is interesting to note that the cluster of earthquake towards northeast lies in Kangra valley where the great Kangra earthquake of 1905 occurred. The region is still seismically very active where earthquakes of moderate intensity followed by aftershocks occurred in 1968 and 1978.

## Pong Dam

Three hundred eighty three, nine hundred seventy seven and three hundred twentysix earthquakes were recorded within 100 km from the dam during October 84-September 85, October 85 - September 86 and October 86 - September 1987 respectively. During the year October 1984 - September 1985, seismic activity increased during May 1985 when water level was decreasing and was close to minimum (Fig. 1). Thereafter, increase in activity during August 85 was noted when water level was increasing. A similar increase was also noted during the year October 85 to September 86 but the large number of earthquakes observed during this year are attributed to the aftershock activity of the Dharamshala earthquake of April 26, 1985 (M 5.7) whose epicentre was 49 km from the dam. Increase in activity was also seen during September 1986 when the water level was increasing similar to that observed in the previous year. The pattern of earthquake occurrence during October 1986 to January 1987 indicated that the number of earthquakes decreased to minimum during June 1987 and started increasing thereafter. The analysis during this year was based on studying the rate of change of water level per month to correlate the occurrence of earthquakes with the reservoir level.

## Pandoh Dam

During the period October 1984 to September 1987,182, 182 and 183 earthquakes were recorded respectively within 100 km from dam for the observations from October to September each year. During the period October 84 to September 85, water level did not vary much and no correlation with the water level was discernible. Significant seismic activity occurred during December 84 and September 85. An earthquake of magnitude 4.2 occurred at a distance of about 20 km from the dam on 11.3.85 which had a focal depth of about 7 kms. The water level variation between maximum and minimum was only 5 meters from October 85 to September 86. There was an increase in seismic activity in December 85 and January 86 when water level was minimum. Similar correlation was also observed around Pong Dam area during the previous year. An increase in seismic activity was not noticed during August 1986 when water level was minimum. An earthquake of magnitude 4 occurred on 22 April 1986 at a distance of about 19 km from the dam. The study of frequency of earthquakes based on water level and monthly change in water level during the period October 86 to September 87 showed partial correlation between the changes in the water level and the number of earthquakes.

## Salal Dam

During the period October 84 to September 85, an increase in seismic activity from March 85 onwards was noted with peak activity during August 1985. Spatial distribution shows that the earthquakes whose epicentre could be determined around the dam site are few in number. During the period October 85 to September 86 the seismic activity remained uniform till May 1986 with the rate of 16 earthquakes during each month. The activity was reduced from June 1986. Spatial distribution showed that during the year, three earthquakes of magnitude between 3 and 4 occurred at a distance of about 70 km from the site. During the period October 86 to September 87 the reservoir level was filled from April 87. The earthquake within 100 kms from the dam were generally of the magnitude 3.2.

## Bhakra Dam

The events monitored in this region did not indicate any direct relationship with the reservoir level. It may be clarified that at present only one seismological observatory is functioning at Bhakra Dam and the data from Pong and Pandoh Dams are being used for epicentral determination in this region which need not necessarily provide proper constraint for focal depth determination unless a close network of local stations is established.

The above analysis brings to highlight the following important aspects :

1. No significant earthquake occurred around the dams in Northwest Himalayas even though they are located in seismically active region where an earthquake of magnitude 8 to 8.5 may occur in the vicinity of the Himalayan boundary faults.

2. In general no correlation between the seismic activity and the reservoir level could be noticed so far even after several years of impounding of the dams at Pong, Pandoh and Bhakra. A weak correlation between them noticed occasionally raises the question whether the induced seismicity in this region takes a much longer time to be discernible as compared to that in a few cases in the Peninsular India due to the complexities of the tectonics in the region.

3. In view of very large recurrence rate of great earthquakes in the Himalayan region, the probability of occurrence of a damaging earthquake in the vicinity of the dam becomes exceeding low during its lifetime.

## Modified Asperity Model for Koyna and Bhatsa Regions

The Asperity model of Kanamori (1986) is characterised by the following phases :

(a) normal seismicity (b) swarms (c) foreshock (d) mainshocks (e) immediate aftershock (f) late aftershock.

The characteristics of normal and reservoir associated earthquakes are found to be similar upto the first five phases. As explained earlier, the late aftershocks show a very slow decaying trend in Omori's law which are controlled by the pore pressure variations in the case of reservoir associated seismicity.

However, the decay constant 'h' for the reservoir induced seismicity (Gupta and Rastogi, 1976) could not distinguish it from the tectonic earthquakes since similar order of values have been reputed in both the cases. Based on the Asperity models it is inferred that the criteria did not work because it was generally computed from the data of immediate aftershocks. However, for reservoir associated seismicity, the role of late aftershocks assumes greater importance. It is, however, difficult to evolve a distinctive criteria for transition between immediate and late aftershocks. However, by monitoring decay constant from the yearly number of earthquakes at successive intervals of time, the late aftershock phase may be considered to have been reached as soon as decay constant starts decreasing below 0.8 which is the lowest value recorded for a tectonic earthquake so far.

It may be mentioned that in the Koyna region, the number of microearthquakes, though decreasing very slowly, is still of the order of 2500 during 1987 even after a lapse of 20 years. Compared to this, the residual seismicity for Bhatsa region is of the order of 300 per year which is attributed to the similar magnitude of the main shock ($M_L$ 4.8). On the basis of residual seismicity which is the last phase of asperity model, a schematic model can be worked out from the trend of microearthquakes near Koyna dam. The largest foreshock and aftershock had similar magnitude of 5.0 and during the last twenty years two earthquakes of similar magnitude have occurred during 1973 and 1980. Thus the largest aftershocks are occurring with an increasing interval of time and their magnitude does not exceed 5.0. Keeping in view the occurrence of earthquake of 1764 of magnitude 6.5 in the same region (Kelkar, 1968), it may be noted that it took about 200 years for earthquake of similar magnitude to recur during December 1967. The continuing active phase of the aftershock activity thereafter in the Koyna region does not allow the energy to accumulate. Recurrence of earthquake of magnitude 6.5 in the region is, therefore, ruled out in the near future. Since the energy accumulates at a slower rate than that released through smaller events, earthquakes upto magnitude 5.0 take place. The slight decrease of microearthquakes and the decay constant also indicate a very slow decay. It may be inferred that the magnitude of the largest aftershock may also gradually decrease below 5.0. The pattern of aftershock occurrence can be shown by a schematic diagram (Fig. 2). This model suggests that in the zones of reservoir associated seismicity, the largest impending earthquake magnitude may not exceed that of the largest aftershock and would be decreasing in future with a progressively larger recurrence interval. Extending this model to the Bhatsa tremors, one may surmise that since the magnitude of largest aftershock was 4.0 during January 84, the largest impending earthquake in the vicinity of Bhatsa reservoir may not exceed magnitude 4.0.

It may be interesting to point out that the rapid decline in seismic activity around Bhatsa region after the seismic activity during 1983-84 indicated that perhaps there may not be a revival of seismic activity. However, the modified asperity model did suggest that largest earthquake upto Magnitude 4 in Bhatsa region cannot be ruled out in the near future which indeed occurred on 2 June 1990 as predicted (Srivastava et al. 1989).

Similarly during August this year when an astrological prediction was made about the possibility of earthquake in Koyna region, there was considerable panic. The application of the modified asperity model could, however, be of great help in reducing the panic in such cases as the largest earthquake expected in the Koyna region would not exceed magnitude 5 in the near future which could cause only very slight damage. The modified model, therefore, helps us in quantifying earthquake risk around Bhatsa and Koyna regions.

## CONCLUSIONS

The above study brings out the following conclusions :

1. No significant increase in seismic activity has occurred in and around the dams in Northwest Himalayas so far.
2. The schematic model proposed for the Koyna seismic activity after the mainshock when applied to Bhatsa region predicted successfully the recent earthquake of 2 June 1990 (M 4.0).

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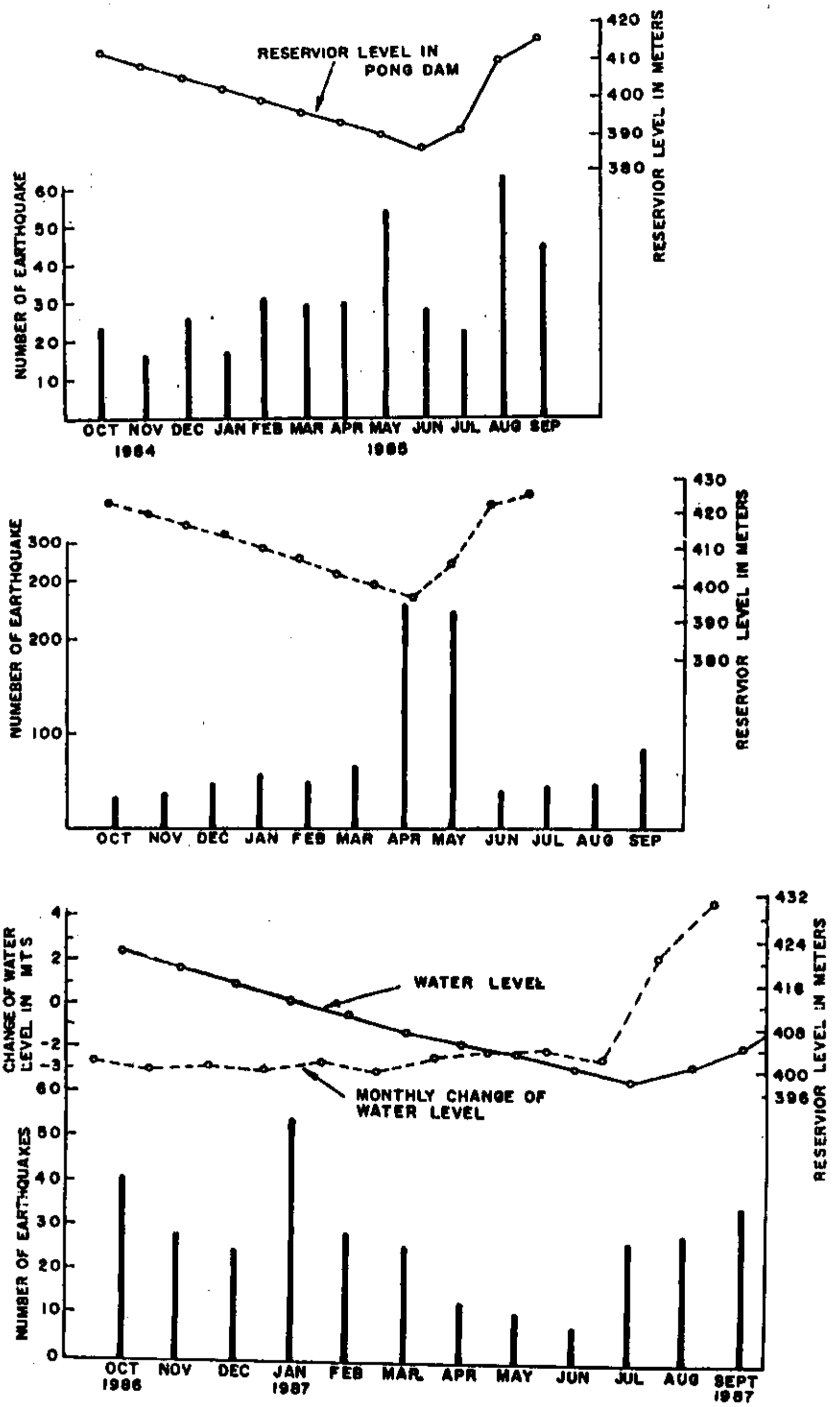
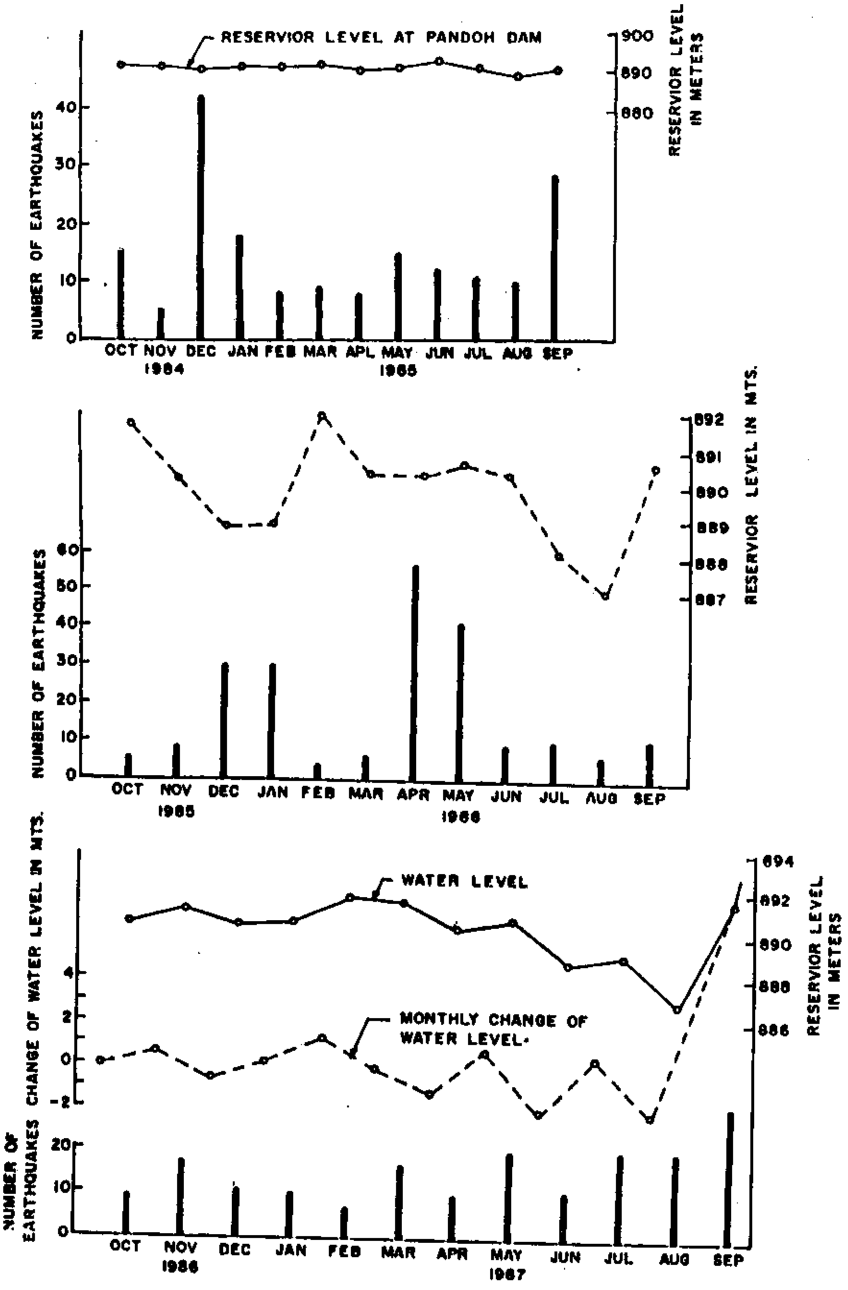


**PONG DAM**

Fig. 1 (A)

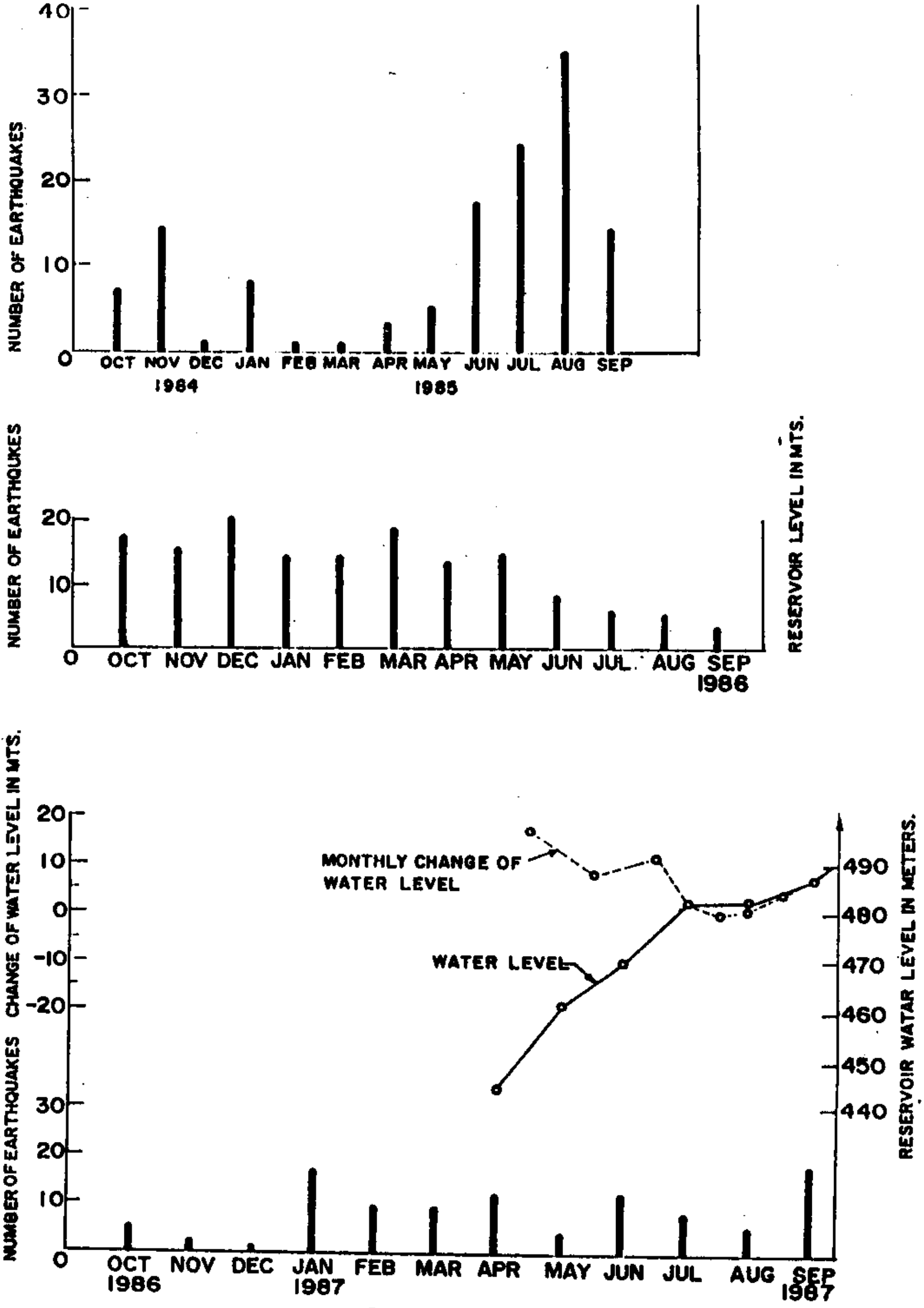
Seismic Activity and Reservoir Level around Pong Dam.



PANDOH DAM

Fig. 1 (B)

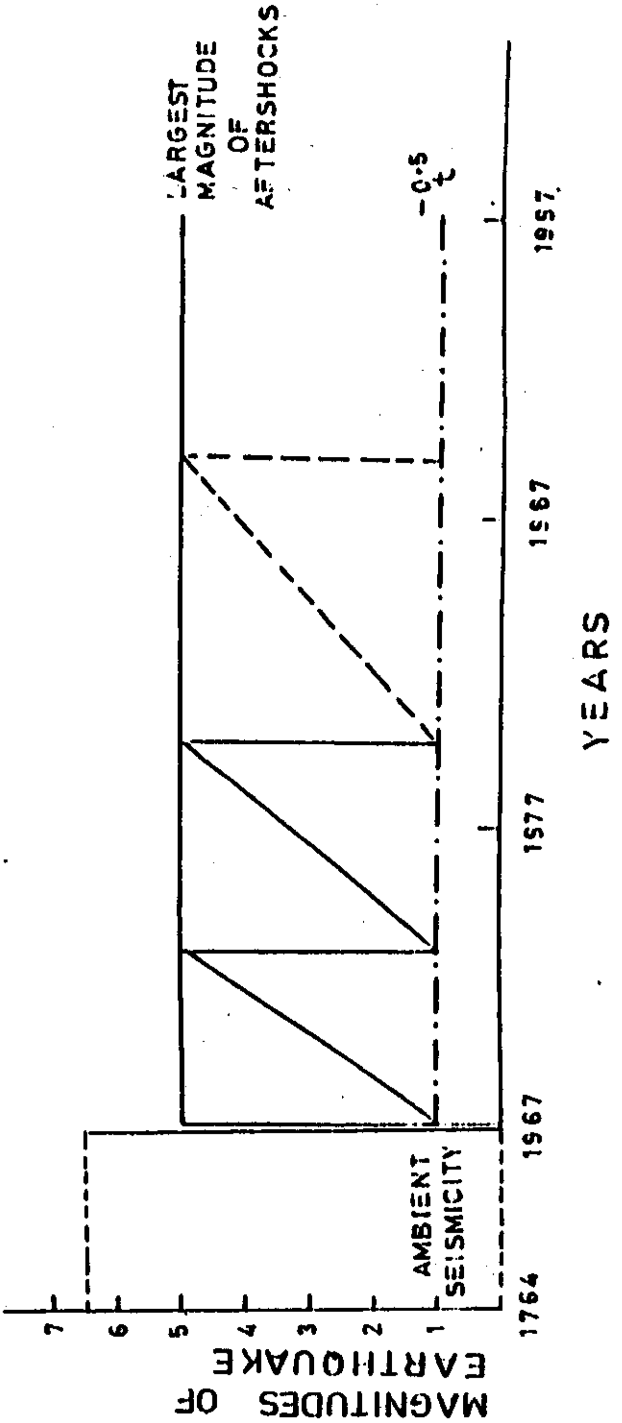
Seismic Activity and Reservoir Level around Pandoh Dam.



SALAL DAM

(Fig.1 C)

Seismic Activity and Reservoir Level around Salal Dam.



(Fig. 2)

Modified Asperity Model for Reservoir Associated Seismicity Around Koyna Region